Chapter II.—SOME FACTORS AFFECTING THE DISTRIBUTION OF ALGÆ AT WOODS HOLE AND VICINITY.

1. THE COAST.

The shore line of Woods Hole, of the Elizabeth Islands, and of neighboring regions along Vineyard Sound and Buzzards Bay is in some respects remarkably varied (see chart 225), but lacks certain important physical features present in other localities. The coast, wherever exposed to wave action or tide currents, is composed of bowlders and stones or consists of sandy and stony beaches. This is because the bowlders and stones have remained at the shore line as the finer material of the glacial deposits covering this region was washed away by the erosion of the coast. The sheltered coves, bays, and harbors will generally have a sandy or muddy shore, sometimes gravelly, with scattered groups of stones or bowlders. There are also small salt marshes connected with some of the coves, as at Quisset and Hadley Harbor. There are no outcroppings of rock, except in the vicinity of New Bedford Harbor, to make possible perpendicular or slanting ledges and rock pools. An account of the geography of the region, together with the character of the shores, is given in section I, chapter II, pages 28 and 29.

For the reasons stated above one misses some of the very characteristic associations of algæ which may be noted in tide pools and along the sides of rock masses where there is opportunity for the development of conspicuous bands or zones of vegetation between tide marks and below—associations that are well illustrated in such localities as Newport and at Nahant, near Boston. A shore of bowlders presents a broken line at the water's edge which can not show to full advantage the distribution of algæ in zones. There are good illustrations of zonation in places, but they are on a comparatively small scale and become evident only as groups of rocks or parts of the shore are studied in detail, as was done for Spindle Rocks in the harbor of Woods Hole, to be described later (pages 476–479). Another factor that works against the conspicuous zonation of algæ in this region, is the relatively small tide, which does not give much opportunity for the development of broad zones of differentiated algal growth.

2. THE BOTTOM IN DEEPER WATER.

As would be expected in an area of glacial drift, the bottom offshore and in the deeper portions of Buzzards Bay and Vineyard Sound may consist of sand, gravel, or stones, with or without deposits of mud, but is frequently of a more or less mixed or spotted character. Channels swept by swift tides are likely to be stony and sandy, while sheltered coves, bays, or other regions, free from the scouring action of tidal currents, usually have a muddy bottom. The ledges or other areas composed of bowlders are simply piles of stones heaped together where they were laid after the finer matrix of the glacial drift had been washed away. The muddy bottoms are due to deposits of silt where the water is sufficiently quiet because of its depth, or because of the absence of tidal currents or wave action sufficiently strong to prevent the accumulation and settling of finer material. A detailed description of the bottom characters will be found in section I, chapter II, pages 29–33, and the peculiarities are graphically presented on chart 227.

The luxuriance and to a large extent the nature of the algal vegetation depends upon the character of the bottom. Rocky, stony, and shelly bottoms are the most favorable for the attachment of algæ and, in general, support the heaviest growths of marine vegetation. Sandy and muddy bottoms are less favorable and are generally very barren, although some species are confined to such situations. It is clear that the shifting nature of sand and mud, frequently stirred by tides and storms, presents conditions very unfavorable for the germination of algal spores, which quickly become covered by sediment. Sandy or muddy bottoms are, however, apparently necessary for the development of extensive beds of the eel grass, *Zostera marina*.

3. THE TIDES AND TIDAL CURRENTS.

As stated before, the tides at Woods Hole and adjacent portions of Buzzards Bay and Vineyard Sound are of relatively slight amplitude. There is considerable variation at different points in the Bay and Sound and in the harbor of Woods Hole, due to the peculiarities of the tidal currents in the region. At Woods Hole, on the Sound side, and in Vineyard Haven the average tide is 1.7 feet, at Gay Head it is 3 feet, in Buzzards Bay at Woods Hole 4.1 feet. With such small tides it is clear that the strip along the shore habitable for a littoral algal flora—that is, a flora above the lowest tide mark—could not be very broad. It is generally only a few feet wide, and one notices at once in this region that the receding tide fails to expose broad stretches of rock, sand, or mud in the manner characteristic of the coast north of Cape Cod, where the tides are much greater.

The arrangement of the land that bounds Vineyard and Nantucket Sounds is responsible for the remarkable tidal currents that flow east and west in Vineyard Sound, and in and out of Buzzards Bay through the channels of Woods Hole, Robinsons Hole, and Quicks Hole. These tidal currents must be very effective in distributing algal spores, and it seems probable that the rapidity with which algal vegetation springs up after each change of season (as over areas scraped clear by floating ice) must be due, at least in large measure, to the tidal currents. It is certain that any alga which develops large crops of spores has by such means the opportunity of distributing these very rapidly throughout practically all of the waters of this region. This factor must be of considerable importance in securing the almost universal presence of some species that can grow under a wide range of life conditions, as well as the appearance of others at distantly separated stations.

4. THE EFFECT OF ICE.

The upper portions of Buzzards Bay are at times during the winter more or less completely frozen over, and small harbors, such as Little Harbor at Woods Hole, may have a thick covering of ice. Sheltered portions of the coast, which are not exposed to surf or stong tidal currents, are fringed with ice. There is also much floating ice in the Bay and Sound consisting of large cakes which come from the breaking up of larger masses. This floating ice is swept by the tides back and forth in the Bay and Sound and through such channels as Woods Hole.

The movement of the ice along the shore and through the channels, whether due to the rise and fall of the tide, to storms, or to tidal currents, serves to scrape bare the large stones and bowlders, wherever they are exposed, so that they are frequently almost or entirely free from algæ in the spring when the ice disappears. These effects are particularly evident on the exposed shore line of the upper portion of Buzzards Bay and in portions of Vineyard Sound, where the rocks in the winter are not only bare of algæ, but also at times free from the common barnacle (*Balanus balanoides*) which covers their surfaces in the summer. This action of the ice along exposed shores and channels thus prevents or greatly reduces the littoral growth during the winter, when the conditions are most favorable for the development of a very characteristic flora, with species of the rockweeds (Fucaceæ) as the most conspicuous forms. If it were not for these facts we should expect in the winter heavy fringes of rockweeds along the shore, for these grow luxuriantly where they are not exposed to the scraping of the ice, as, for example, along the shore of Cuttyhunk and elsewhere in the lower portion of Buzzards Bay and the westerly portion of Vineyard Sound.

The scraping effects of ice on a particular group of rocks may be better understood by comparing chart 267 of Spindle Rocks with chart 274 and the charts that show the coming in of the spring and summer floras after the ice has disappeared (charts 268, 269, and 270). Rocks which are perfectly bare after the winter become thickly covered during the spring and summer with algæ characteristic of these seasons.

5. DEPTH OF WATER.

Buzzards Bay and Vineyard Sound are relatively shallow bodies of water. As may be seen from chart 227, at only a few stations was a depth greater than 18 fathoms obtained. There were a number of stations with a depth between 14 and 17½ fathoms, but by far the larger number in the middle regions of both Bay and Sound were between 8 and 14 fathoms. The Bay in general gradually deepens toward the lower portion, but the Sound, on the contrary, shows no marked progressive deepening toward the western end.

The depth at which algæ will grow is determined chiefly by the penetrating power of light and consequently varies in different seas according to the relative amount of sunshine during the year and the clearness of the water. Rosenvinge (1898, p. 233) places 20 fathoms as about the limit of growth for algæ in northern seas where, however, the proportion of cloudy and foggy days is very large. Börgesen (1905, p. 700) found the limit of growth around the Faroes to be between 25 and 30 fathoms. In southern seas, where there is a very large proportion of sunny days and more direct penetration of the sun's rays, as in the Bay of Naples and off the Balearic Islands (Rodríguez 1888) in the Mediterranean, deep-water algæ have been reported to grow at 50 to 100 fathoms. Most of the species at these great depths belong to the Rhodophyceæ, but there are many of the Phæophyceæ in water deeper than 50 fathoms, and several species of the Chlorophyceæ are found at 20 to 60 fathoms.

With respect to the amount of sunlight during the year Woods Hole probably stands somewhat midway between the conditions over northern seas and those of the south. It certainly has both in winter and summer a large proportion of fair and sunny days. Consequently there are no parts of either Buzzards Bay or Vineyard Sound included in the limits of the survey that are too deep for certain algæ. The dredgings of the Survey at the deepest stations have shown abundant growths of algæ wherever the bottom was suitable, but two of the deepest stations in the westerly portion of Vineyard Sound (7682 and 7683, 19 and 19½ fathoms, respectively) were over a sandy bottom unfavorable for the attachment of algæ. Station 7670 (19 fathoms), in Buzzards Bay west of the island of Penikese, showed a stony bottom with many plants of *Laminaria Agardhii* var. *vittata*, and in small quantity *Champia parvula*, *Chondrus crispus*, *Ceramium rubrum*, *Grinnellia americana*, *Polysiphonia urceolata*, and *Rhodymenia palmata*.

6. LIGHT.

As stated above, the depth to which certain algæ may descend depends upon the penetration of light. The factor that determines the lowest limits of algal life is not depth of water but absence of light.

The Cyanophyceæ, or blue green algæ, and the Chlorophyceæ, or green algæ, require the greatest illumination and are rarely, if ever, found at Woods Hole and vicinity in water more than 2 or 3 fathoms deep, but are for the most part near the surface or between tide marks. The Rhodophyceæ, or red algæ, reach the lowest depths, although many species grow near low-water mark and some even above it. The Phæophyceæ, or brown algæ, are somewhat midway between the green and the red algæ in their light relations. Some species of the brown algæ grow at low-water mark and above, but many grow below low water and to a considerable depth; few, however, are found at the greater depths of the red algæ. There are apparently no regions in Buzzards Bay and Vineyard Sound too deep for certain species of brown algæ, for *Desmarestia aculeata*, *Laminaria Agardhii*, and *Laminaria Agardhii* var. *vittata* were found between 17 and 19 fathoms. The list of red algæ present at these depths (17 to 19 fathoms) is, however, much longer: *Champia parvula*, *Chondrus crispus*, *Cystoclonium purpurascens* var. *cirrhosum*, *Delesseria sinuosa*, *Grinnellia americana*, *Phyllophora Brodiæi*, *Phyllophora membranifolia*, *Plumaria elegans*, *Polysiphonia elongata*, *Polysiphonia urceolata*, *Rhodymenia palmata*, *Spermothamnion Turneri*.

There is therefore in a broad sense a distribution of algæ in zones depending upon light relations, the blue-green and green algæ growing under the brightest illumination, the brown algæ requiring on the whole less light, and the red algæ able to flourish under the weakest illumination. It must constantly be borne in mind, however, that there is always an overlapping in the habitat of species among these groups, many brown and red algæ growing side by side and even with the green algæ under very bright illumination.

It is a matter of dispute whether the life habits of marine algæ with respect to illumination are influenced chiefly by the quality of the light or by the quantity. The red rays of sunlight, it is claimed, can not penetrate much below 7 fathoms, and the light at greater depths is mainly composed of blue and green rays, is feeble in yellow, and lacks red rays entirely. Certain investigators, notably Engelmann (1883, 1884) and Gaidukov (1902, 1904, 1906), hold that the quality of the light rather than its intensity determines the distribution of the green, brown, and red algæ. According to this view the green algæ grow under bright illumination because they require the maximum of red rays, while the red algæ are able to live in deep water because their color allows them to absorb the green rays which they especially need. The brown algæ in general adjust themselves to light conditions intermediate between these extremes. It is well known that a number of the Rhodophyceæ which grow near the surface of the water are colored, not the characteristic red of this group, but shades of brown and green; for example, the Irish moss, *Chondrus crispus*, is frequently green under bright illumination in the summer at Woods Hole. Furthermore, Nadson (1900) has shown that certain species of the Cyanophyceæ and Chlorophyceæ, which are green near the surface, take on reddish colors in deep water.

These conclusions that the colors of algæ depend upon the quality of the light are opposed to views held by Berthold (1882), Oltmanns (1892), and others who have considered the Rhodophyceæ to be merely shade plants, the distribution of which was determined by the quantity of light. They have made much of the fact that in dimly lighted caves and shaded situations red algæ, which usually grow at some depth, are found very near the surface; but it should be borne in mind, as Börgesen (1905, pp. 702, 703) points out, that while these algæ receive a much weaker white light in these caves, they may have the benefit of much blue and green reflected light.

Gaidukov (1902, 1906), in a series of interesting experiments, has shown that certain algæ (species of *Oscillatoria*, *Phormidium*, and *Porphyra*) take on complementary colors when subjected to pure rays from a spectrum, becoming, for example, green under red and yellow light and red or purplish under green or blue light. This phenomenon, called complementary chromatic adaptation, is shown only by living plants and is believed to involve changes in the structure of the pigments. The reason why green algæ can not live in deep water is clear, since the red rays upon which they depend are not there present. The red algæ, on the contrary, may live at the surface as well as at depths below the penetration of red rays, but at the surface they meet the competition with green algæ from which they are free in deep water.

However, it can not be said that all of the phenomena are clearly explained by the hypothesis of chromatic adaptation held by Engelmann and Gaidukov. Thus, Rodríguez (1888) reports the following Chlorophyceæ off the Balearic Islands at much greater depths than would be expected for any of the green algæ: *Palmophyllum orbicularis* Thuret, 130 meters; *Cladophora pellucida* Kützing, 40 meters; *Codium tomentosum* Agardh, 48 meters; *C. tomentosum* var. *elongatum*, 90 to 100 meters; *Udotea Desfontainii* Decaisne, 120 meters; and somewhat similar records are known for certain of the Chlorophyceæ in the Gulf of Naples.

7. TEMPERATURE AND SEASONAL CHANGES.

The temperature of the water, the depth, and the character of the bottom are the chief factors in determining the distribution of the algæ in the region covered by the survey. The influence of temperature must be of fundamental importance where the seasonal extremes are as great as those of the summer and winter at Woods Hole. The conditions in the winter would admit a rich northern or boreal algal flora at Woods Hole were it possible for the species to reach this sheltered situation by traveling around Cape Cod and to survive the warm summer. As it is, a number of northern species do grow at Woods Hole in the favorable winter and spring seasons and some are able to vegetate through the summer. In striking contrast with the winter's cold is the summer temperature, which is so high that it can support a flora with many points of resemblance to the floras of warmer seas. The subject of temperature receives considerable attention in section I, chapter II, pages 38–52, where the detailed records of the Survey are presented in a series of tables, and likewise on charts 211 to 214, giving the location of the stations.

The average monthly temperature of the water off the Government wharf in Great Harbor, Woods Hole, for the years 1902–1906 (five years) is given in table 10, page 47, and the seasonal changes are portrayed graphically in chart 219. It will be seen that during January, February, and March the mean temperature was below 35° F. The period when the temperature was below 35° actually extended from about December 25 to March 15, and this may be considered the winter season. After March 15 the temperature rose rapidly, passing 60° about June 1; this constitutes a spring season. Between June 1 and October 12 the temperature remained above 60°, holding between 69° and 71° from July 11 to August 28, a period of 48 days; this is the long summer season of warm water. After October 12 the temperature fell rapidly from 60°, until December 11, when it reached 37°, and it remained between 37° and 35° until December 26, when it passed below 35°; this period may be considered the autumn season. A table of averages such as that of table 10 does not give the extremes of temperature, the lowest of which was 28½° in January and February, and the highest 74° in July and 74.5° in August. It should also be remembered that the extremes are much greater in situations more sheltered than Great Harbor, Woods Hole, as, for example, in the upper portions of Buzzards Bay, where the water may be heavily frozen for several weeks and the summer temperature probably rises close to 80°.

It is very important to contrast the seasonal range of temperature at Woods Hole with that of the bottom water between Gay Head and the ledges of Sow and Pigs, for in this region of the survey the range of temperature is the least. On August 16, 1907, the bottom temperature off Gay Head was 57.2° F. (16¾ fathoms) and 59.2° (11¾ fathoms), off Sow and Pigs 60.1° (10½ fathoms), and in Vineyard Sound between these two points 55° (17¾ fathoms); the surface temperature at these stations was from 3° to 5° higher. On November 12, 1907, the bottom temperature off Gay Head was 51.9° (10½ fathoms), off Sow and Pigs also 51.9° (8 fathoms), and in Vineyard Sound between these points 52° (18 fathoms); the surface temperature at these points was about 1° lower. On March 20, 1908, the bottom temperature off Gay Head was 36.6° (8 fathoms), off Sow and Pigs 36.6° (5 fathoms), and in Vineyard Sound between these two points 37.4° (18 fathoms); the surface temperatures being almost the same. On June 6, 1908, the bottom temperature off Gay Head was 57.6° (12½ fathoms), off Sow and Pigs 55.1° (7½ fathoms), and on June 5 in Vineyard Sound between these two points 53.3° (18 fathoms); the surface temperature at these points was then from 1° to 3° higher. These data are presented in tabular form below, the surface temperature being given above the line and the bottom temperature below.

	Aug. 16, 1907.	Nov. 12, 1907.	Mar. 20, 1908.	June 5–6, 1908.
Off Gay Head	$\frac{63.8°}{57.2°}$ (16 fath.) $\frac{62.4°}{59.2°}$ (11¾ fath.)	$\frac{50.7°}{51.9°}$ (10½ fath.)	$\frac{36.8°}{36.6°}$ (8 fath.)	$\frac{59.3°}{57.6°}$ (12½ fath.) (June 6)
Off Sow and Pigs	$\frac{63.1°}{60.1°}$ (10½ fath.)	$\frac{51.2°}{51.9°}$ (8 fath.)	$\frac{36.5°}{36.6°}$ (5 fath.)	$\frac{56.1°}{55.1°}$ (7½ fath.) (June 6)
Between Gay Head and Sow and Pigs	$\frac{60.3°}{55°}$ (17¾ fath.)	$\frac{51.2°}{52°}$ (18 fath.)	$\frac{36.7°}{37.4°}$ (18 fath.)	$\frac{57°}{53.3°}$ (18 fath.) (June 5)

These records of the bottom temperature between Gay Head and the ledges of Sow and Pigs indicate that the average range is from below 35° in the winter to about 60° in the summer. The bottom temperature probably does not fall to the lowest winter temperature of the sheltered waters of the Bay and Sound and does not rise to within 15° of the highest summer temperatures in such situations; the total range is close to 26°. The surface temperature between Gay Head and the ledges of Sow and Pigs is at times in the summer 4° to 5° higher than the bottom temperature, and in the winter probably somewhat lower; the total range is close to 32°. The seasonal range in Great Harbor, Woods Hole, is about 46°, and it must be more than 50° in the upper portions of Buzzards Bay.

The causes of these very different conditions are not difficult to understand. The great range of temperature in the sheltered waters of the Bay and Sound is simply the result of summer and winter atmospheric temperatures acting on bodies of water sufficiently shallow to respond very quickly to their influences. Tables 9 and 10 (pp. 46–47), giving the average monthly range of the temperatures of both air and water at Woods Hole over a five-year period, make clear the relationship, also shown on chart 219. The small range of the temperature of the bottom water between Gay Head and the Sow and Pigs, together with the greater range of the surface water, shows the effect of proximity to the deeper cold water of the open sea, water which, as stated before, appears to be an extension of the cold belt north of Cape Cod.

It is clear from the above statements of the seasonal ranges of temperature in the two extremes of the conditions presented within the limits of the Survey (first, the bottom temperatures off Gay Head and Sow and Pigs; second, the temperatures of sheltered waters of the Bay and Sound) that several very different types of floras would be expected, and this is the case. The uniformly cool bottom water of Gay Head and the Sow and Pigs (generally below 60°) admits of the development of a flora with a number of species characteristic of northern waters. This flora is restricted to the lower portion of Buzzards Bay and the westerly portion of Vineyard Sound and is distinguished by the presence of the following species which are never found (at least during the summer) in the more sheltered regions of the Bay and Sound: *Chætomorpha melagonium*, *Laminaria digitata*, *Plumaria elegans*, *Rhodomela subfusca*, *Actinococcus peltæformis*, *Gymnogongrus norvegicus*, *Euthora cristata*, *Lomentaria rosea*, *Rhodymenia palmata*, *Delesseria sinuosa*. It would be very interesting to know whether other northerly species may not be present during the winter and spring and whether this cold-water flora extends its range during the winter into more sheltered portions of the Bay and Sound, but we have made no dredgings for algæ off Gay Head in the winter and know nothing of the deep-water flora of that season.

The seasonal extremes in the sheltered portions of Buzzards Bay and Vineyard Sound, as would be expected, give at least two distinct seasonal floras, (1) that of the winter and early spring, and (2) that of midsummer and the early autumn. Some species are found all the year round, but they are generally much more luxuriant at one season than at the other. Many of the species are limited to a season of perhaps two or three months and are never found at other times. It is not at present possible to discuss satisfactorily the seasonal habits of the algæ at Woods Hole, for they have been very little studied during the winter, but such data as are known are included in the Catalogue.

The study of Spindle Rocks (pages 476–479) has shown in a rather surprising way the degree of change which takes place on a small mass of rocks over a 12-month period.

The northerly species which would be most likely to invade the Bay and Sound during the favorable winter season would be forms that reproduce rapidly through large crops of spores and mature so quickly that several generations may develop during the season. The tidal currents of the region would serve to distribute such species very widely, even though the favorable season might be short.

8. SALINITY OF THE WATER.

There are no fresh-water streams of importance in the immediate vicinity of Woods Hole to affect markedly the salinity of its waters, which are not much less dense than the open sea, having an average density of about 1.024 (the density of water in the north Atlantic being from 1.027 to 1.028). In the westerly portion of Vineyard Sound and lower portion of Buzzards Bay the density is somewhat greater, having been found at one point as high as 1.0243 (November, 1907). In the extreme upper portion of Buzzards Bay the density is considerably less than at Woods Hole, having been recorded as low as 1.0212 (March, 1908). Details of the observations on density made by the survey are presented in section I, chapter II, pages 52–54.

The lower density of the upper portion of Buzzards Bay is evidently due to the proximity of a number of small streams that empty into the head of the Bay, but these are too far removed from Woods Hole to influence materially the salinity of the water at that point. The swift tidal currents of Vineyard Sound keep its waters fairly uniform in density. It is not probable that density is a factor of importance in determining the distribution of algæ in the deeper waters of the Bay and Sound, and it certainly is not to be compared with the two chief factors of temperature and the character of the bottom.

The only bodies of brackish water in the immediate vicinity of Woods Hole are those of small ponds or areas of salt marsh which are connected with the sea by channels and rendered saline in various degrees by the inflow of tides or during storms. Such brackish waters support characteristic floras totally unlike those of the Bay and Sound proper, well illustrated by the *Lyngbya* salt-marsh association and the *Enteromorpha* salt-marsh association (see page 456).